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Observations on the Life History of the Goldeye, Hiodon Alosoides (Rafinesque), in Moccasin Bay on the Little Missouri Arm, Garrison Reservoir, North Dakota

Robert N. Hieb

OBSERVATIONS ON THE LIFE HISTORY OF THE GOLDEYE, *HIODON ALOSOIDES* (RAFINESQUE), IN MOCCASIN BAY ON THE LITTLE MISSOURI ARM, GARRISON RESERVOIR, NORTH DAKOTA

by

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This thesis submitted by Robert N. Hieb in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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ABSTRACT

The life history and population structure of goldeye, Hiodon alosoides (Rafinesque), in Moccasin Bay, Garrison Reservoir, North Dakota, were investigated during 1966 and 1967. This species had not been commercially exploited in this impoundment, but current populations indicate that a commercial fishery can be supported.

A gill net fished from the surface to the bottom captured 885 goldeye in 1966. Total-length, weight, and sex were recorded and scale samples collected. The length-frequency of the catch was plotted, and average rate of growth of seven year-classes was calculated by examination of scales from 365 fish. Length-weight relationships and sex ratios were determined. The ages at which sexual dimorphism of the anal fin could be recognized were established.

Experimental gill nets fished in surface waters took 1,601 goldeye in the spring of 1967. Spawning activity and duration were related to surface water temperatures at various reservoir locations. A sex ratio was calculated from 531 fish captured at spawning sites. Fecundity was calculated for each of 25 gravid females, and age at sexual maturity was determined from 25 females and 10 males in spawning condition. Fine-mesh plankton nets were used in unsuccessful attempts to collect spawned ova. Twenty-five stomachs were collected, and the frequency of occurrence of food organisms was noted. Parasitic helminths were collected from the alimentary tracts of 30 goldeye, and all were identified as Bothriocephalus cuspidatus Cooper.

INTRODUCTION

Garrison Reservoir, largest of the main-stem impoundments on the Missouri River, was primarily constructed for purposes of flood-control, navigation, irrigation, hydro-electric power, and recreation. In addition to the sport fishery, a vast commercial fishery potential was created. In recent years, carp, Cyprinus carpio Linneaus; carp-sucker, Carpiodes carpio Linneaus; black bullhead, Ictalurus melas (Rafinesque); channel catfish, Ictalurus punctatus (Rafinesque); large-mouth buffalofish, Ictiobus cyprinellus (Valenciennes); and smallmouth buffalofish, Ictiobus bubalus (Rafinesque), have been taken successfully by various commercial operations (Hildebrand, 1967).

However, this reservoir's largest population of potentially valuable commercial fishes has remained virtually untapped. Records of the North Dakota Game and Fish Department indicate goldeye, Hiodon alosoides (Rafinesque), to be one of the two most abundant species in the impoundment (Duerre, 1965; Hill, 1966, 1967), but despite their abundance, goldeye have not, as yet, been taken commercially from Garrison.

An intensive goldeye fishery has been established in the Canadian provinces, and markets there are excellent. In the United States, goldeye have been taken from limited areas of Minnesota and Montana, and successfully marketed in Canada. The availability of goldeye in Garrison Reservoir, and the close proximity of the

Canadian market, suggest that commercial exploitation might be feasible in the near future. The present study was therefore undertaken to investigate the life history and population structure of Garrison Reservoir goldeye, which would be of fundamental value in the future commercial management of the species.

DESCRIPTION OF THE AREA

Garrison Reservoir

Garrison Dam at Riverdale, North Dakota, was closed in April, 1953. The impoundment at capacity contains 24,500,000 acre-feet of water and has an area of 326,000 acres (Neel, 1963). The reservoir is 200 miles in length, has an average width of three miles, a maximum depth of 180 feet, and has approximately 1,600 miles of shoreline (Duerre, 1965). The largest of main-stem impoundments on the Missouri River, Garrison is confined to northwestern North Dakota, and was constructed by U. S. Army Corps of Engineers as a multi-purpose unit.

Tributaries

In addition to the Missouri River, two major tributaries enter the reservoir. The Yellowstone River joins the Missouri at the northern end, near Williston, North Dakota. The Little Missouri River flows northward and eastward through badlands areas, and enters the impoundment approximately 50 miles due west of Garrison Dam.

Physiography

The topography ranges from fairly smooth, rolling plains which surround the main body of the reservoir, to the rough local badlands which are encountered in the southwest. Shorelines are more irregular in the Little Missouri arm, due to inundation of these badlands, with many small bays bounded shoreward by steep bluffs, breaks, and unusual

soil formations. Soils north of the reservoir are of glacial origin; those to the south and west are residual (Duerre, 1965), and are composed of bentonitic clays, shales, and sandstones. Residual soils are especially susceptible to erosion and are responsible for large concentrations of silt which are carried into the reservoir each year, via the Little Missouri River.

Climate

The climate of the area is semiarid or subhumid, and the average annual precipitation is approximately 16 inches, including some 30 inches of snow. Seventy-five per cent of this precipitation occurs between April and October.

Weather records from Williston, North Dakota, are typical for the reservoir area. The maximum summer temperature is 110 F; minimum winter temperatures range from -20 to -60 F (Neel, Nicholson, and Hirsch, 1963). The average July temperature is 69.4 F, and the average January temperature is 7.9 F.

The first killing frost of autumn is approximately 20 September (U. S. Dept. Interior, 1951), and freeze-up occurs late in November. Ice-out generally takes place early in April, and in 1967, this occurred on 17 April in the Little Missouri arm.

Study Area

Moccasin Bay on the Little Missouri arm was chosen as the site for the present study (Fig. 1), because it is easily accessible and is sheltered by high bluffs from prevailing northwesterly winds. The bay is located approximately seven miles west of the actual river-reservoir

confluence, and is about three miles long, one-half mile wide, and has a maximum depth of approximately 65 feet.

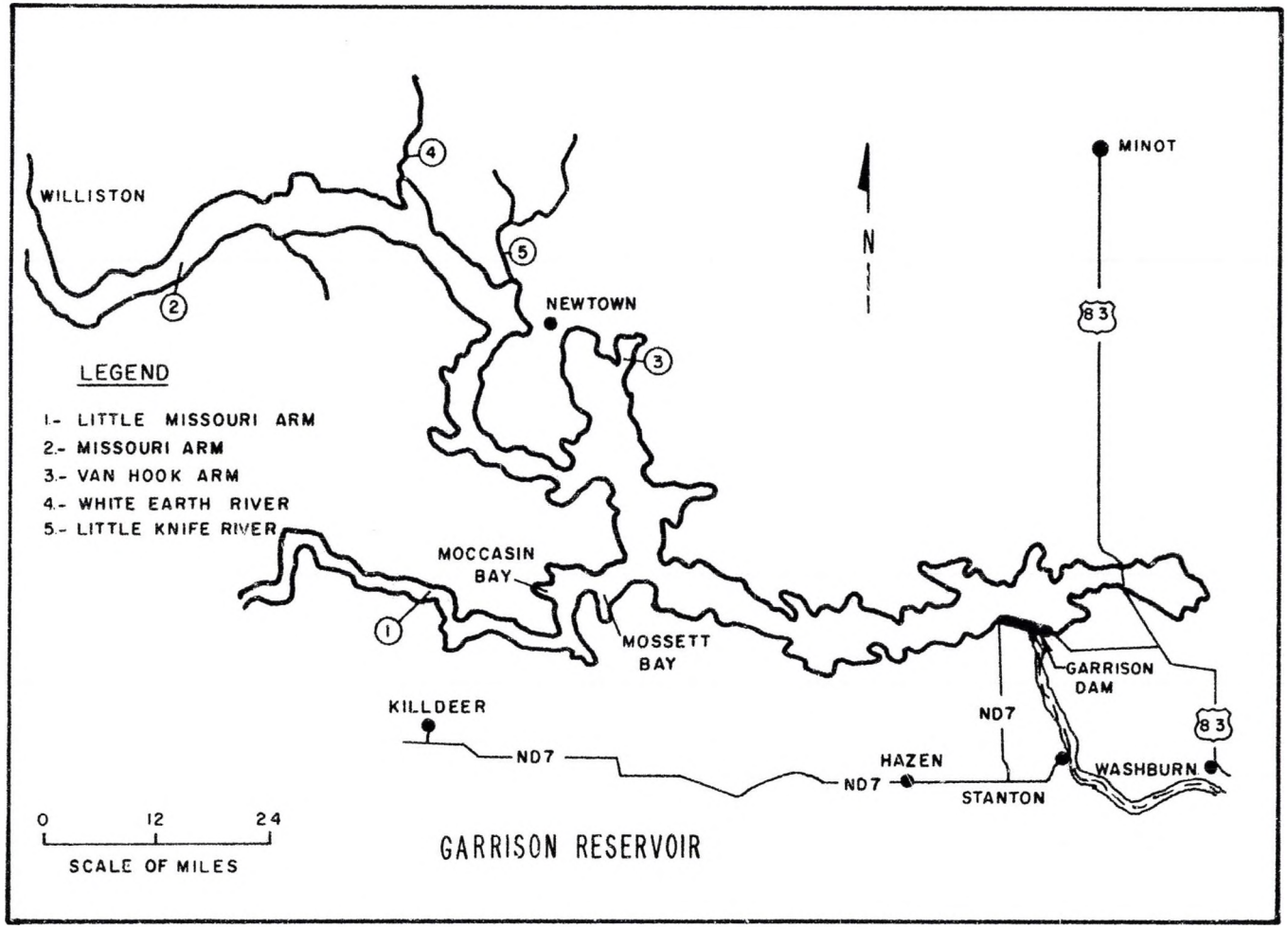


Fig. 1. Garrison Reservoir, North Dakota

LITERATURE REVIEW

There is a paucity of published material concerning the goldeye. Most previous investigations have been concerned with growth rates of this species in Canada and the northern United States, where commercial interest in goldeye is greatest. Bajkov (1930) discussed the economic importance of this fish in the Province of Manitoba, and in a summary of fisheries investigations in the prairie provinces, presented growth rates and life history findings for this species in Canadian waters. He reported that the food of goldeye was quite variable, but consisted mostly of terrestrial and aquatic insects, and their larvae, which were taken in surface waters at night. From observations made at Lakes Winnipeg and Winnipegosis, Hinks (1943) reported that approximately half of the large female goldeye spawned in any one year. Battle and Sprules (1960) were the first to discover that goldeye ova were bathypelagic, or semi-buoyant; this had been suspected in 1948, when windrows of goldeye eggs were found along the shore of Lake Claire, Alberta. Fine-mesh nets were used to collect eggs and larvae at the surface of the water, and complete descriptions of the eggs and early developmental stages of the goldeye were reported.

Van Oosten and Deason (1957) reviewed the status of the goldeye in the Red Lakes fishery, Minnesota, from 1917 to 1938, and reported that this species accounted for 6.6% of the average annual catch, and that 97% of the yearly catch of goldeye was taken during the summer

season. Eddy and Carlander (1943) determined the growth rates for Minnesota fishes, and aged 625 goldeye from Red Lake. Further studies of goldeye in the commercial fishery of the Red Lakes were conducted by Grosslein and Smith (1959), who reported various life history findings and changes in the population status. They found a marked decline in the production of goldeye, which was accompanied by increased fishing effort; there was no evidence that this decline could be attributed to an increase in predator species. The size of year-classes had declined but the number of age-groups apparently had changed little. Age and the rate of growth were determined from 1,165 specimens, and a positive correlation was found between fluctuations in summer air temperatures and the growth rate. There was a predominance of males in the sex ratio; of 389 goldeye, 56% were males and 44% were females. The food habits of goldeye were also studied and it was found that terrestrial insects were predominant, suggesting that goldeye frequently feed on the surface in shallow water. The common occurrence of noctuid moths and fireflies in the stomachs led the authors to speculate that goldeye feed at night.

Martin (1952) conducted the only age and growth study of goldeye in the southwestern United States. Eight hundred seventeen specimens from Lake Texoma, Oklahoma, were aged, and their growth rates were calculated. In addition, sexual dimorphism of the anal fin of mature goldeye was described and illustrated; the lower edge is concave or straight in the females, and convex, or lobed, in the males. Young-of-the-year fish were not taken during the study, even though panels of 3/4 inch mesh were fished. Of 889 goldeye collected, 72.1% were

females and 27.9% were males. In another Lake Texoma study, Self (1954) investigated the parasites of several fish populations, and discovered pseudophyllidean cestodes in the alimentary tracts of goldeye; these differed from Bothriocephalus cuspidatus, Cooper (1917), and were named Bothriocephalus texomensis n. sp., Self (1954).

In the Missouri River impoundments, Claflin (1963) summarized age and growth data of goldeye from Lewis and Clark Lake, South Dakota, and the sixty miles of river below Gavins Point Dam. Hill (1965) studied life history of the goldeye in the Fort Peck area, Montana, and reported ages and growth rates. The fecundity of Montana goldeye was calculated, and averaged 6,913 eggs per female. In Fort Peck Reservoir, female goldeye comprised 70.9% of 450 captured fish, while males accounted for only 29.1% of this number. Movement studies of tagged goldeye were conducted but achieved limited results due to the small number of returns. Peterson (1967) investigated goldeye depth distribution in Moccasin Bay of Garrison Reservoir, North Dakota. Limnological conditions of turbidity, temperature, and oxygen concentration were sampled concomitantly and were correlated with the vertical distribution of goldeye; these three factors did not appear to greatly influence distribution. Peterson suggested that goldeye depth distribution was affected by photoperiod and feeding habits of the species. Benson (in press) summarized limnological and fisheries findings for all main-stem reservoirs on the Missouri River, and reported that goldeye are much more abundant in Garrison and Fort Peck than in the downstream reservoirs. Comparison of growth rates revealed that the goldeye of Garrison Reservoir grew the slowest. Goldeye and

their principal foods were also investigated in Lewis and Clark Lake, and bottom fauna and fish were the predominant food organisms found.

METHODS AND MATERIALS

Collection of fish

Field work was initiated in the spring of 1966, and data was collected from 1 June to 5 September. In 1967, the investigation was continued from 15 April to 15 August. During these periods, goldeye were taken by vertical, depth gill nets; horizontal, surface gill nets; electrical shocking gear; and seines. Of the methods listed, gill nets, set for periods of 12 to 14 hours, captured the greatest number of fish.

In 1966, a 36 x 50 foot vertical gill net, of graduated mesh size, was fished from the surface to the bottom, in conjunction with a concurrent investigation relating depth distribution to limnological conditions (Peterson, 1967). Goldeye taken with this net were studied for age and growth patterns, sex ratios, and sexual dimorphism. Electrical shocking equipment, small frame nets, and seines were used briefly during the late summer months of 1966, in an attempt to capture young-of-the-year specimens.

In 1967, 125 x 6 foot experimental gill nets, of graduated mesh size, were buoyed to fish the surface waters. Goldeye taken in these nets were studied for fecundity, stomach contents, and parasites. These nets were an invaluable aid in locating spawning populations of goldeye and in repeated checks of spawning progress and duration.

Age and growth

Goldeye were removed from the nets and field data was taken from them as quickly as possible, to avoid error due to shrinkage from exposure. Total lengths were measured to the nearest tenth of an inch, and weights, recorded to the nearest gram, were taken on a spring balance scale (Hanson Dietetic Scale, Model 1460). Scale samples were taken from the left side of each fish above the lateral line just below the dorsal fin, as prescribed by Rounsefell and Everhart (1953).

Length-frequency. All goldeye captured during 1966 were measured and assigned to various inch-groups. The population structure, by total lengths, was then determined by construction of a length-frequency table (Peterson, 1967).

Age determinations and growth history. Scales from 365 fish taken during August, 1966, were soaked in water for ten minutes, scrubbed clean of dirt and mucous, rinsed, and mounted between glass slides. At least three scales from each fish were studied to elimimate spurious scales and possible error. Scale images were projected and magnified by means of a Bausch and Lomb micro-projector. Paper strips were superimposed upon these images (Lagler, 1952), and scale length was marked from the focus to the lateral margin. The position where each annulus intercepted the strip was also marked. A straight-line relationship between scale length and body length was assumed. Average, annual growth increments for each year class were computed with the aid of nomographs.

Length-weight. The length-weight relationship was determined according to the method of Rounsefell and Everhart (1953). Logarithmic

conversions were made for the lengths and weights of 84 representatives of different inch-groups, the correlation between length and weight was resolved, and the resulting best fit curve was plotted for the growth rate of Moccasin Bay goldeye. Average age-group size, as obtained from the growth history phase of this study, was then superimposed on the length-weight curve.

Sexual determinations and dimorphism

The sex of all goldeye taken in 1966 was determined by examination of the gonads. Sex was recorded as male, female, or unknown. Ratios of males to females was calculated only from fish positively identified as to sex.

Sexual dimorphism has been reported in mature goldeye based on the shape of the anal fin which is concave in the female, and lobed or convex in the male. During this study, goldeye sexed by gonad examination were inspected for corresponding anal fin development. The ages of all fish sexed were determined by scale studies, and the number of fish sexed which also exhibited the characteristic fin development was recorded. The data was compared to determine the validity of sexual determinations in the various age-groups, based on external characteristics.

Fecundity

In the spring of 1967, gravid goldeye were collected from spawning areas of Moccasin Bay. Female fish were carefully removed from the nets and opened along their ventral margin, and the left and right ovaries were removed and preserved in 10% formalin. The samples were

allowed to harden in the formalin solution for several days to facilitate handling. They were then washed to remove detritus and excess formalin, and drained on blotting paper. Any adhering mesentery or viscera was then removed.

Ovaries from five fish were weighed (Dial-O-Gram Scale; Ohaus Scale Corp.), and all eggs in each pair of organs were counted. Ovaries from 20 additional goldeye were weighed, but counts were restricted to five to ten gram portions of each sample. An estimate of eggs per unit weight of ovaries was obtained by fitting a regression line to data from these 25 samples, using the least squares method (Rounsefell and Everhart, 1953).

Ripe male goldeye received but brief attention; however, lengths, weights, and scale samples were taken from ten male fish which readily released spermatozoa upon handling. A correlation between sexual maturity and size and age was made.

In association with fecundity studies, an attempt was made to locate spawning areas and determine the duration of the spawning period. Throughout the spawning season, surface temperatures of both the probable spawning sites and the open waters were recorded in degrees Celcius with a mercury thermometer (Scientific Products), and water temperature was later correlated to the above factors.

Collection of spawned ova

Methods were devised to determine whether spawned ova of the goldeye could be collected from the open waters. A number twenty mesh plankton net (Turtox Supply House), 9½ inches in diameter, was equipped with a wire harness and a small collection vial at the trailing end.

Twenty feet of 1/4 inch polyethylene rope, attached to the harness, facilitated trailing of the net. This was fished at various depths for periods of approximately five minutes. At the end of each run, the net was retrieved, and the contents of the sample vial examined for the presence of ova. Areas sampled included both the open, pelagic waters of the bay and those more sheltered inlets where test gill netting had indicated spawning activity. In addition, weathered beaches were searched for eggs washed ashore by wind action.

Stomach analysis

Twenty-five stomachs were collected from obviously distended mature goldeye. The entire stomach, with small portions of the alimentary tract both anterior and posterior to it, was removed and preserved in 10% formalin. Subsequently, these were opened and their contents washed into Pietri dishes and examined with a Bausch and Lomb dissection microscope. On several occasions, stomachs were opened and the contents observed while in the field. Forage fishes recovered were identified, measured, and this information was recorded. However, attempts at a thorough analysis of stomach contents were not made and samples were not preserved for further study.

Parasite examination

A complete parasitic investigation of Moccasin Bay goldeye was not attempted. However, 30 alimentary tracts were removed from fish and examined for the presence of helminth parasites. Specimens were collected and preserved in 10% formalin for further study.

RESULTS

Catch composition

Analysis of the catch taken with the vertical gill net during June, July, and August, 1966, revealed a total of 1,661 fish representing 12 different species, including goldeye; yellow perch Perca flavescens (Mitchill); channel catfish; black bullhead; white crappie, Pomoxis annularis (Rafinesque); walleye, Stizostedion vitreum (Mitchill); sauger, Stizostedion canadense (Smith); European carp; northern pike, Esox lucius Linnaeus; smallmouth buffalofish; carpsucker; and freshwater drum, Aplodinotus grunniens (Rafinesque). Of the total, 885 fish were goldeye, comprising 53.28% of the catch (Peterson, 1967).

Age and growth

Length-frequency. The 885 goldeye taken during 1966, ranged in total length from 4.5 to 18.0 inches. Few specimens were encountered which exceeded 13 inches. Three hundred eighty-nine fish were between 10 and 12 inches long, representing almost 44% of the total (Fig. 2; Peterson, 1967).

Growth history. Examination of scales from 365 fish indicated seven year-classes to be present, 1959 through 1965. Of the sample, 100 fish were of age I; 47 were of age II; 88 were of age III; 103 were of age IV; 25 were of age V; 1 was of age VI; and 1 was of age VII (Table 1). Young-of-the-year goldeye were not taken from Moccasin Bay during the study.

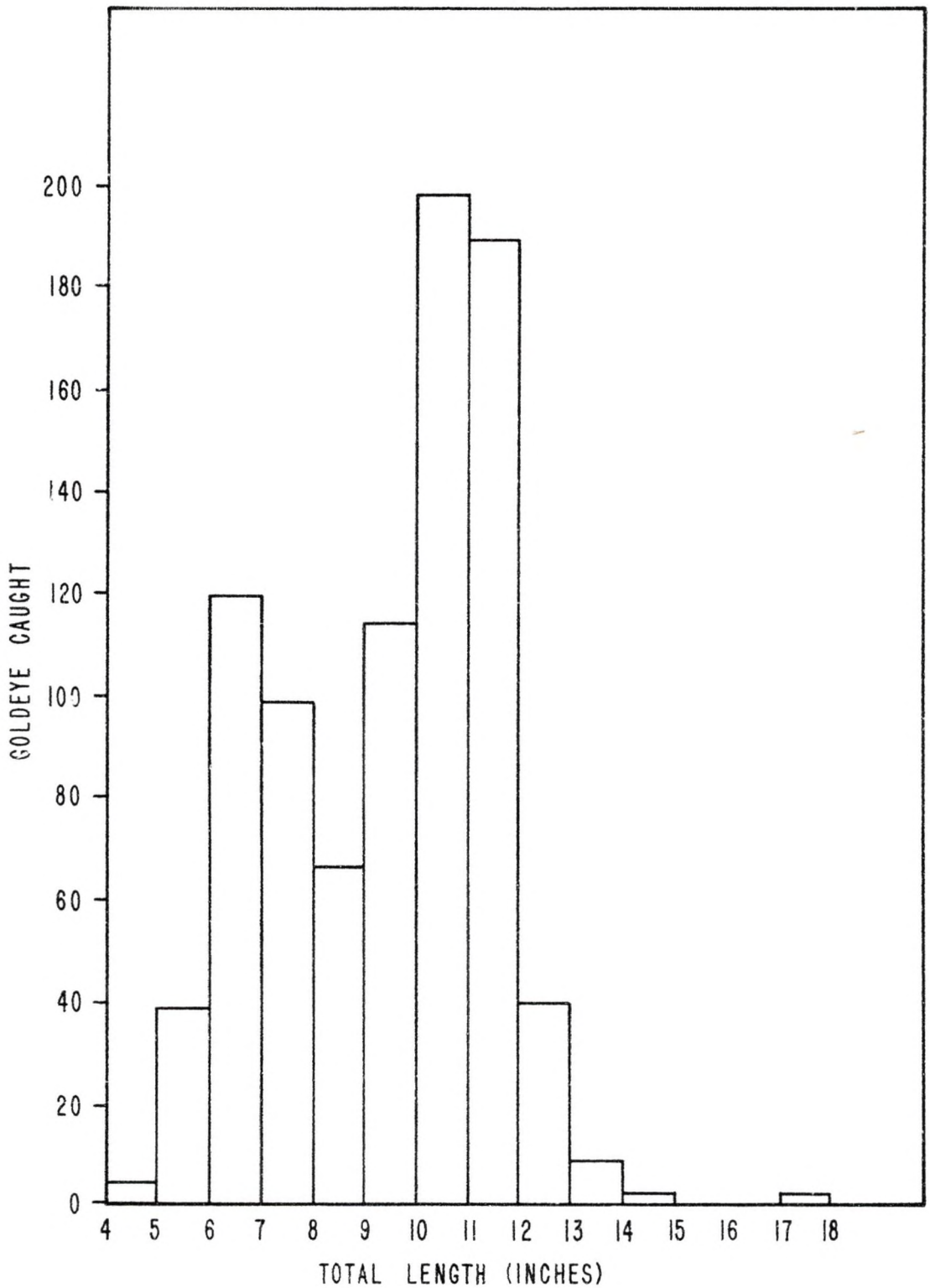


Fig. 2. Length Frequency of Moccasin Bay Goldeye, 1966 (After Peterson, 1967)

TABLE 1

AGE AND GROWTH OF MOCCASIN BAY GOLDEYE

Age Group	No. Fish	Yr. Class	Mean Calculated Total Length at Annulus (Inches) I	II	III	IV	V	Range in L. at Capture
I	100	1965	4.5					5.1 - 7.3
II	47	1964	3.7	7.1				7.6 - 10.0
III	88	1963	4.4	6.9	9.1			8.9 - 11.6
IV	103	1962	4.7	7.8	9.6	10.7		9.9 - 14.5
V	25	1961	5.2	8.0	9.7	10.7	11.5	10.9 - 15.2
VI*	1	1960	-	-	-	-	-	- 11.3 -
VII*	1	1959	-	-	-	-	-	- 18.0 -
Total	365	Average	4.5	7.5	9.5	10.7	11.5	

*Average computed growth is not indicated for these year-classes, due to small sample size.

Goldeye of the combined year-classes averaged 4.5 inches total length at age I; 7.5 inches at age II; 9.5 inches at age III; 10.7 inches at age IV; and 11.5 inches at age V. These figures represent mean annual growth increments of 4.5 inches, 3.0 inches, 2.0 inches, 1.2 inches, and 0.8 inches during the first five years of life, respectively. Growth rates were plotted by a method which permitted graphic comparison of growth patterns for the year-classes over the past five-year period (Fig. 3).

Length-weight. The lengths and weights of 84 fish were used to establish a statistical relationship between these two factors. The general formula, $W = cL^n$, was resolved to be Log W =-.9273 + 3.0683 Log L for Moccasin Bay goldeye, and the best fit length-weight curve appears in Figure 4. The mean lengths of age-groups I through V, as determined by growth study, are superimposed on this curve. The smallest fish included in this sample was 5.1 inches in total length, weighed 30 grams, and belonged to age-group I. The largest encountered in the study was a female, 18.0 inches in total length, which weighed 831 grams; it was in age-group VII.

Sex ratios and dimorphism

Sex determinations were made on 241 goldeye taken during June and July, 1966, of which 75 were males and 166 were females, or a ratio of 1 to 2.2, respectively. During August, a sample of 234 fish was composed of 78 males and 156 females, for a sex ratio of 1 to 2.0. The composite average of these two samples yielded a ratio of 1 male to 2.1 females for the Moccasin Bay area (Table 2).

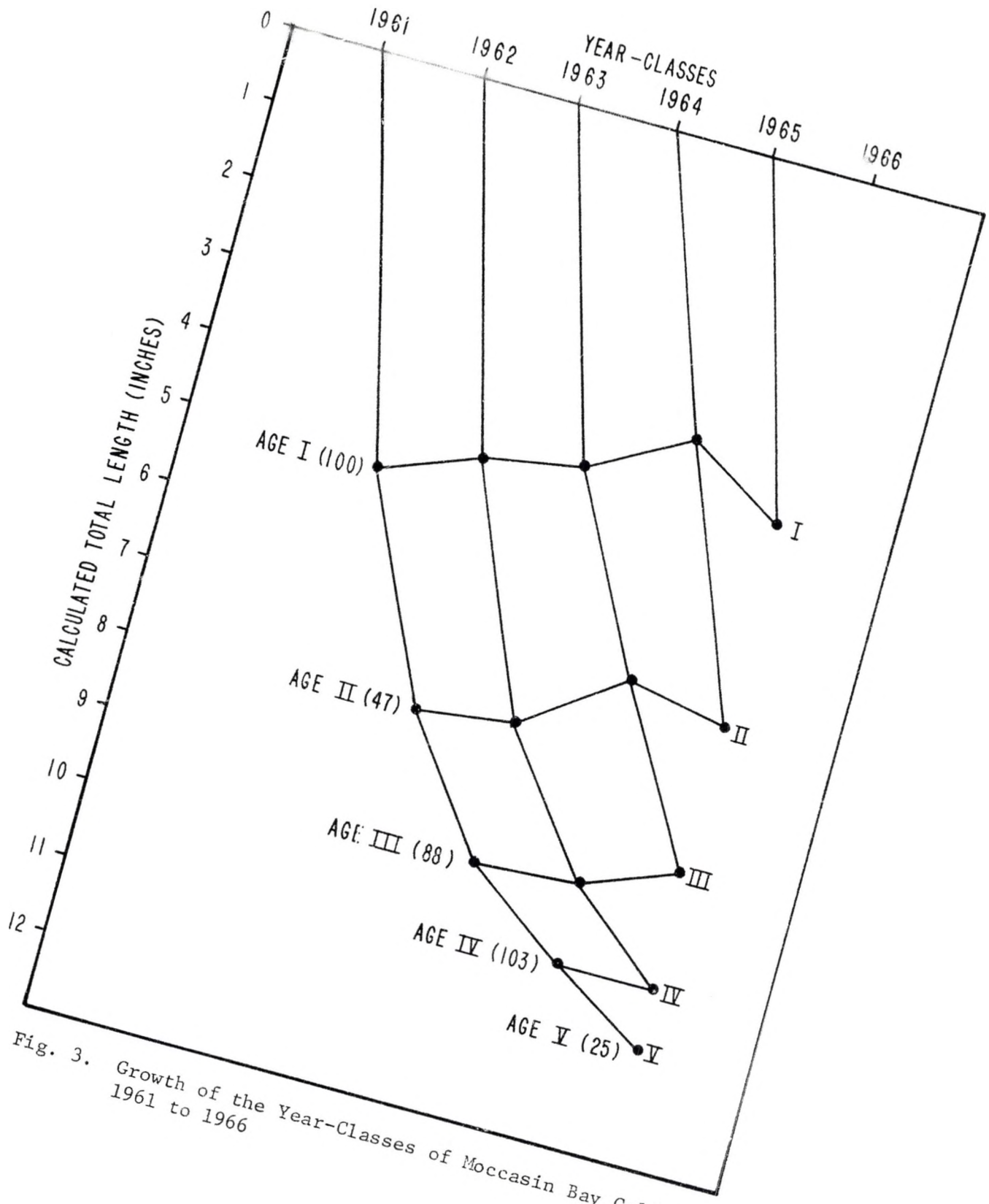
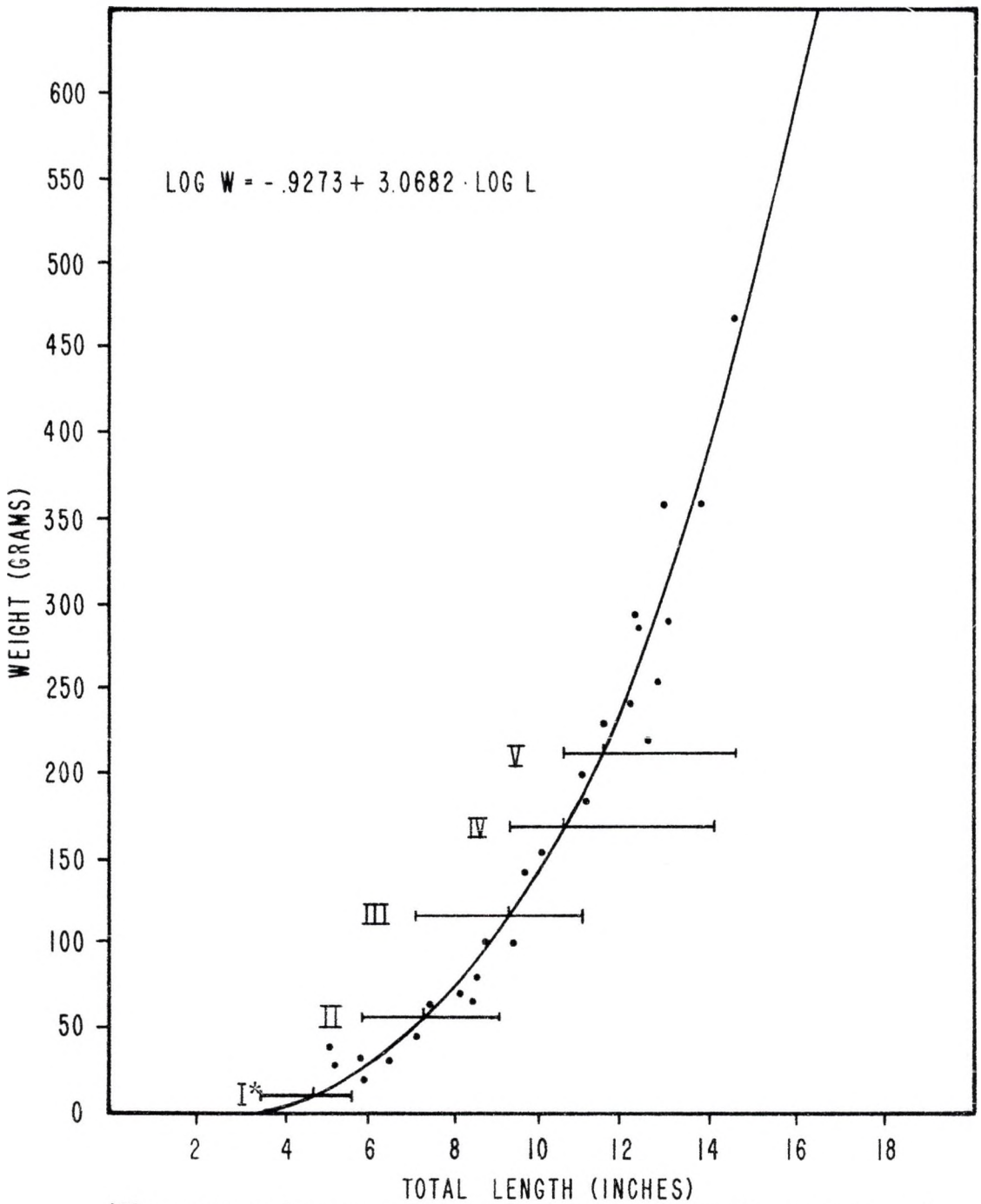


Fig. 3. Growth of the Year-Classes of Moccasin Bay Goldeye, 1961 to 1966



*The mean and range of calculated total lengths at time of each annulus formation.

Fig. 4. Relationship Between Length and Weight of Moccasin Bay Goldeye, 1966

TABLE 2

SEX RATIOS OF MOCCASIN BAY GOLDEYE

Sample No.	Total No. Fish	No. Males	No. Females	Per Cent Males	Per Cent Females	Ratio*
June, July 1966 1	241	75	166	31.1	68.9	1 : 2.2
August 1966 2	234	78	156	33.3	66.7	1 : 2.0
Totals	475	153	322	32.2	67.8	1 : 2.1

*The Ratio of male to female goldeye.

A third ratio was calculated from fish captured from 8 June through 21 July, 1967 in Moccasin Creek. Of 501 mature goldeye, 151 were males and 350 were females, or a ratio of 1 to 2.3, respectively.

Fish from which scales had been collected for age and growth determinations were sexed by examination of the gonads. Corresponding dimorphic development of the anal fin appeared first in the second year of growth. Distinct sexual dimorphism was found in 46.8% of the goldeye in age-group II; 94.3% of those in age-group III; 99.0% in IV; and 100% in age-groups V, VI, and VII (Table 3).

Fecundity

Fecundity was calculated for each of the 25 gravid specimens, by use of the formula $Y = -145.63 + 202.9.X$ (Fig. 5). The number of ova per female ranged from a low of 3,304 to a high of 10,060 (Table 4), and the average number of ova for the total of 25 specimens was 6,531. Of the sample, 16 fish were of age-group IV and showed a mean fecundity of 5,897, while eight fish were of age-group V, with a mean fecundity of 7,359. Ten ripe males were also aged, and length and weight data was recorded (Table 5). Of these, four were of age-group III, five were of age-group IV, and one was of age-group V.

Spawning activity and duration

From 20 May to 3 June, 824 goldeye were collected in Mossett Bay, an area some three miles east of Moccasin Bay and near the Little Missouri-Missouri River confluence. Of this number, 23 fish, or 2.8% of the total catch, were gravid females. The surface water temperatures of Mossett Bay during this period averaged 11.7 Celcius (Table 6).

TABLE 3

AGE AND DIMORPHISM IN MOCCASIN BAY GOLDEYE

Age Group	Goldeye Examined for Sex	Goldeye Exhibiting Anal Fin Dimorphism	Per Cent Exhibiting Anal Fin Dimorphism
0	0	0	0.0
I	100	0	0.0
II	47	22	46.8
III	88	83	94.3
IV	103	102	99.0
V	25	25	100.0
VI	1	1	100.0
VII	1	1	100.0

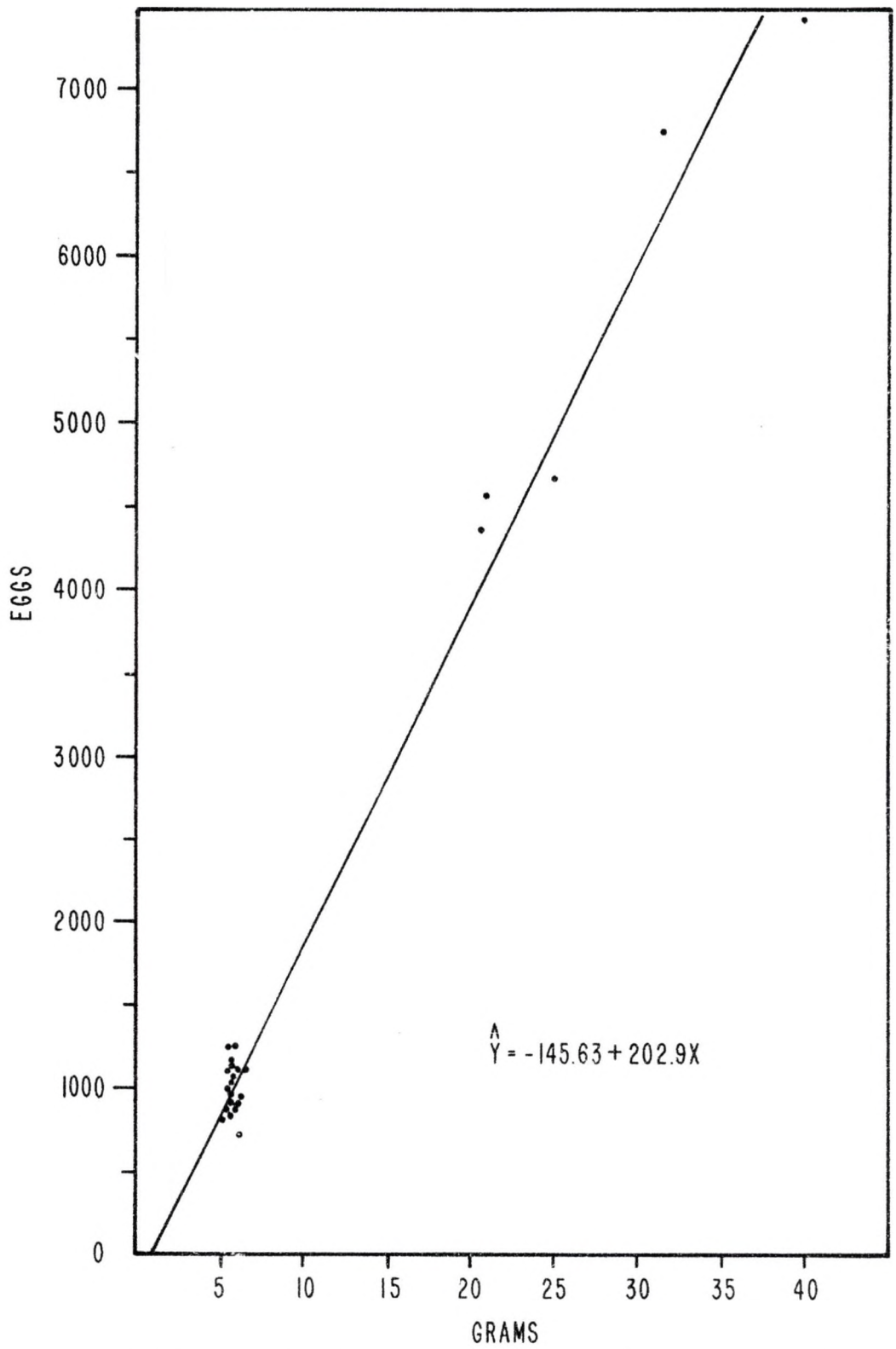


Fig. 5. Relationship Between Number of Eggs and Ovary Weight of Moccasin Bay Goldeye, 1967

TABLE 4

COMPUTED FECUNDITY OF MOCCASIN BAY GOLDEYE

Fish No.	Age Group	Total Length (Inches)	Total Weight (Grams)	Ovary Weight (Grams)	Computed Fecundity (Y= -145.63 + 202.9.X)
1	IV	11.1	220	20.8	4075
2	IV	11.8	210	32.6	6469
3	IV	11.9	216	34.0	6753
4	IV	11.9	241	25.7	5069
5	IV	11.9	254	23.5	4623
6	IV	12.0	216	30.6	6063
7	IV	12.1	218	34.4	6834
9	IV	12.1	240	26.6	5252
11	IV	12.1	244	31.1	6165
13	IV	12.2	252	17.0	3304
14	IV	12.3	236	25.3	4988
15	IV	12.3	276	41.2	8214
17	IV	12.5	260	34.3	6814
18	IV	12.5	298	40.1	7991
19	IV	12.6	251	29.0	5738
21	IV	12.9	264	30.3	6002
16				Average	5897
8	V	12.1	232	28.3	5596
10	V	12.1	240	26.8	5292
12	V	12.1	272	31.4	6225
16	V	12.4	300	35.4	7037
20	V	12.6	279	39.3	7828
22	V	13.0	332	50.3	10060
23	V	13.2	316	41.3	8234
24	V	13.2	316	43.1	8599
8				Average	7359
25	VI	13.9	352	50.2	10040
1				Average	10040
Total No. Fish	25			Sample average	6531

TABLE 5

AGE AND SIZE OF RIPE MALE GOLDEYE

Fish No.	Total Length (Inches)	Total Weight (Grams)	Age Group
1	10.6	148	III
2	10.9	174	IV
3	11.2	204	IV
4	11.2	212	V
5	11.3	190	IV
6	11.3	190	IV
7	11.5	212	IV
8	11.7	221	III
9	11.7	230	III
10	12.3	219	III

TABLE 6

RELATIONSHIP OF WATER TEMPERATURE TO SPAWNING CONDITION OF GOLDEYE

Surface Temperatures at Various Sites (Degrees Celcius) — W* —					Catch of Goldeye					
Date (1967)	Mossett Bay	Moccasin Mouth	Moccasin Bay	Moccasin Creek	Date (1967)	Area of Catch Sample	Total Catch Goldeye	Total No. Females	No. Gravid Females	No. Spent Females
5/20	10.0	-	-	-						
5/21	10.0	-	-	-	5/21	Mossett Bay	287	-**	15	0
5/22	10.5	-	-	-						
5/23	11.0	-	-	-	5/23	Mossett Bay	164	-	3	0
5/24	11.0	-	-	-	5/24	Mossett Bay	220	-	0	0
5/25	12.0	-	-	-						
6/2	14.5	-	-	-						
6/3	14.5	-	-	-	6/3	Mossett Bay	153	-	5	0
					Totals		824		23	
					6/4	Moccasin Creek	85	49	13	0
6/7	13.0	13.5	15.0	16.5						
6/8	13.0	13.5	15.0	16.5	6/8	Moccasin Creek	113	52	15	0
6/9	13.0	13.5	15.0	16.0	6/9	Moccasin Creek	49	33	13	0
6/14	15.5	16.5	17.5	18.0						
6/15	15.5	16.5	17.5	18.0	6/15	Moccasin Creek	70	25	6	0
6/16	17.5	18.0	20.0	20.5	6/16	Moccasin Creek	82	41	11	0
6/17	17.5	18.0	19.0	19.5	6/17	Moccasin Creek	88	51	18	0
6/20	16.0	15.5	15.0	14.5	6/20	Moccasin Creek	65	28	6	0
6/21	16.0	16.0	14.5	17.0						
6/22	16.0	16.0	15.5	17.0	6/22	Moccasin Creek	54	39	13	4

TABLE 6--Continued

Surface Temperatures at Various Sites (Degrees Celcius) —— W* ——►					Catch of Goldeye					
Date (1967)	Mossett Bay	Moccasin Mouth	Moccasin Bay	Moccasin Creek	Date (1967)	Area of Catch Sample	Total Catch Goldeye	Total No. Females	No. Gravid Females	No. Spent Females
6/23	16.0	16.0	15.5	16.0	6/23	Moccasin Creek	33	7	1	0
6/29	19.0	18.0	19.0	21.0						
6/30	18.5	19.0	18.5	19.0	6/30	Moccasin Creek	31	16	1	3
7/5	19.0	19.0	19.5	20.0	7/5	Moccasin Creek	41	32	6	5
7/11	19.5	19.0	19.0	20.0						
7/12	19.5	19.0	19.0	20.0	7/12	Moccasin Creek	15	2	0	0
7/20	24.0	24.0	24.0	25.5						
7/21	24.0	24.0	24.0	26.0	7/21	Moccasin Creek	51	24	0	7
					Totals		777	399	103	19

*Proceeding westward.

**Not recorded.

From 4 June through 21 July, Moccasin Creek, a long, narrow backwater situated mid-way in Moccasin Bay, was sampled. It was observed that the total catch and the size of its components varied in the same area on successive days. There was also a uniformity of individual sizes in these catches. Of 777 goldeye captured, 103 were gravid females, representing 13.3% of total catch and 25.8% of the 399 females taken. During this period, surface water temperatures of Moccasin Creek ranged from 16.5 to 26.0 Celcius, and averaged 18.9 degrees.

Spent females first appeared in the catch of 22 June. The last gravid females were taken on 5 July, when the surface temperature of Moccasin Creek was 20.0 Celcius. Netting was discontinued on 21 July, when seven spent but no gravid females were caught.

During the latter period (4 June through 21 July), a distinct temperature gradient was found in the surface waters, and temperatures gradually increased from the main reservoir westward to the more sheltered areas of Moccasin Bay (Table 6). In addition to Moccasin Creek, temperatures were taken in the open waters of the bay, approximately 1/4 miles east of the netting site; at the mouth of Moccasin Bay, approximately 1 3/4 miles east of the netting site; and at Mossett Bay, some three miles east and within sight of the main stem of the reservoir. The average water temperature in Moccasin Bay was 17.9; at the mouth of the bay, 17.5; and at the Mossett Bay location, 17.4 Celcius. With reference to the Moccasin Creek area, these averages represented decreasing temperature differences of 1.0, 1.4, and 1.5 Celcius, for the three areas, respectively.

Collection of spawned ova

Repeated sampling with a plankton net in the period from 20 May to 16 June, coincided with net catches of gravid goldeye. The Moccasin Creek area, Moccasin Bay, and Mossett Bay were stations sampled. In every instance, examination of collection vial contents failed to reveal the presence of any ova. The exposed beaches of Moccasin Bay were searched but ova were not found.

Stomach contents

Stomachs were collected on four occasions during May and June, 1967. The frequency of occurrence of food organisms in the stomachs was determined for five goldeye collected on each date; the results are presented in Table 7. Additional examinations of stomach contents were made in the field, and numerous adults of the orders Coleoptera, Hemiptera, and Orthoptera were recovered. Four yellow perch, that ranged from three to four inches, were found in goldeye; two were in one sample, while two other samples each contained one perch. An unidentified member of the phylum Nematomorpha was recovered from one sample.

On 22 August, 1967, stomachs were collected from five Moccasin Bay goldeye, when great quantities of insects littered the water surface. All stomachs were extremely distended and contained large volumes of winged male ants of three genera; Tapinoma, Lasius, and Acanthomyops (Peterson, 1967).

Parasites

Pseudophyllidean cestodes were the only helminthes represented in the parasite samples, and all were of one species, Bothriocephalus cuspidatus (Cooper, 1917).

TABLE 7

FREQUENCY OF OCCURRENCE OF FOOD ORGANISMS FROM MOCCASIN BAY GOLDEYE

Organisms	Date	24 May					7 June					8 June					16 June				
	Fish No.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Arthropoda																					
Crustacea																					
Cladocera Sp.																	x				x
Insecta																					
Ephemeroptera																					
Caenis Sp. N.*									x												
Unknown N.									x												
Odonata																					
Unknown N.									x												
Hemiptera																					
Corixidae A.			x		x																
Coleoptera																					
Staphylinidae A.							x														
Scarabaeidae A.							x														
Chrysomelidae A.		x						x		x				x	x	x					
Unknown A.		x					x														
Fragments A.		x		x					x	x		x	x	x	x	x		x	x		
Diptera																					
Culicidae																					
Chaoborus Sp. L.		x																			
Chironomidae																					
Unknown L.		x		x	x	x			x	x	x		x								
Unknown P.													x					x			
Unknown A.								x													

*N = Nymph; A = Adult; L = Larva; P = Pupa.

DISCUSSION AND CONCLUSIONS

Species catchability

Gill nets were the most successful gear for capturing goldeye; few were taken in frame nets. Benson (in press) has reported similar findings. Mesh size below 2 1/2 inches was most effective, and a possible straight line relationship between mesh selectivity and fish size as the mesh size increased from 3/4 to 1 1/2 inches was noted by Peterson (1967). Goldeye appeared to be equally distributed in both the open water and shoreward zones of the reservoir, and both areas produced nearly equal catches from the surface stratum. Sets made near the surface in open waters took few game species; however, similar sets near shore took considerably more game fish. The maximum catch of goldeye was between 1800 and 0600 (24 hour military time), a period coinciding with their activity near the surface.

Catch composition and abundance

Garrison Reservoir appears to support an exceedingly large population of goldeye. Annual summer nettings at 17 different locations have taken large proportions of goldeye. Records obtained from experimental gill netting in an average of 35 feet of water show that 1,115 goldeye were taken in 1964, representing 26.38% of the total catch; 1,927 in 1965, representing 30.68% of catch; and 3,288 in 1966, representing 36.41% of catch (Duerre, 1965; Hill, 1966, 1967). If

the surface waters had been intensively sampled, the proportion of goldeye captured would undoubtedly have been much greater.

Peterson (1967) reported that a total of 1,661 fish of 12 species was taken in Moccasin Bay. Goldeye amounted to 53.28% of the catch, with a total of 885 individuals. These figures suggest that relatively large number of goldeye are present in this area.

In 1952, the U. S. Fish and Wildlife Service recognized that impoundment conditions were conducive to large populations of fishes such as goldeye, carp, and suckers. With reference to Garrison Reservoir, it was predicted that goldeye, among other species, would become numerous and furnish the stock for future commercial fishing ventures (U. S. Dept. Interior, 1952). Current findings indicate that the population of goldeye has increased to the level where it will support a commercial fishery.

Age, growth, and population structure

The exact time of annulus formation in Garrison goldeye was not determined. Most scales examined during late May and early June showed large, peripheral margins of circuli but no distal annuli. However, annuli did appear to be forming at the outer edges of some scales. This is in accord with the findings of Claflin (1963), who reported that annulus formation took place by the third week in June in goldeye from the lower Missouri River.

According to Benson (in press), the goldeye of Garrison have the slowest growth rate found in this species in any of the main-stem Missouri River reservoirs. A comparison of growth rates of Moccasin

Bay goldeye with those from other areas appears in Table 8. Sixty-five per cent of the total calculated growth attained during the first five years of life occurred by the end of the second growing season. Garrison goldeye reached maturity at an early age, and the population was structured around young adults in the ten to twelve inch range. Fish of this size were abundant and were most commonly four years of age. Goldeye longer than twelve inches or older than five years were relatively rare. Apparently, complete turnover of the population occurred over a short span of years.

Attempts were not made to calculate separate growth rates for the sexes. However, Martin (1952) found that the length of female goldeye in Lake Texoma, Oklahoma, exceeded that of males after the third year of life. This appeared to hold true for goldeye from Garrison.

Graphical presentation of growth of combined sexes (Fig. 3) showed little variation among the year-classes or their respective age groups over the past five-year period. Minor differences were apparent, but great increases or decreases in growth were not indicated. The population appeared to be stabilized at present, suggesting regular reproduction and year-class strength.

Scarcity of individuals in age-groups 0 and 1 was largely the result of selectivity in capture methods (gill net mesh sizes) and did not represent their relative abundance in the general population. Shoreline seine hauls during the study contained numerous age I goldeye, which supports suggested regularity of year-class abundance. Young-of-the-year goldeye were not collected in Moccasin Bay, but state fisheries personnel (Hill, personal communication) took them in the upper reaches

TABLE 8

COMPARISON OF CALCULATED TOTAL LENGTHS OF MOCCASIN BAY GOLDEYE WITH THOSE FROM OTHER AREAS

Location	No. Fish	Mean Calculated Total Length at Annulus (Inches) I	II	III	IV	V	VI	VII	VIII
Lake Texoma, Okla. (Martin, 1952)	817	7.5	8.8	11.2	12.6	13.2	14.2		
Red Lake, Minn. (Grosslein & Smith, 1959)	1165	4.1	8.3	11.3	12.9	14.1	15.0	15.8	16.6
Missouri River, S. Dak. (Claflin, 1963)	1167	4.5	7.9	10.5	11.9	12.8	13.5		
Fort Peck, Mont. (Hill, 1965)	747	4.0	8.0	10.2	11.4	12.1	12.9	15.5	16.0
Present Study (1966-1967)	365	4.5	7.5	9.5	10.7	11.5			

of Garrison during late September, 1966. These ranged in total length from 3.6 to 4.6 inches. During August, 1967, young-of-the-year were captured in the upper, turbid stretches of the Little Missouri River (Johannes, personal communication).

Sex ratios

All goldeye investigations to date have reported a lack of balance between the sexes. Two samples from Moccasin Bay goldeye yielded a sex ratio of two females to each male, while a third ratio calculated from fish captured during the time of spawning did not show significant variation. The sex ratio for Fort Peck goldeye (Hill, 1965) was almost identical to that for Garrison.

Sex ratios of the catch changed dramatically in the Little Missouri River, some 25 miles west of Moccasin Bay, where males outnumbered females. A ratio of 1.7 males to each female was calculated from 393 goldeye taken from this area (Johannes, personal communication). Hill (1965) also reported more males than females in most tributaries of Fort Peck Reservoir. Preliminary sampling indicated a gradually changing ratio from the reservoir to upstream areas of the tributary; the causes of this change in sex ratio were not determined.

Sexual dimorphism

Other investigators have discussed and illustrated the sexually dimorphic features of the anal fin (Martin, 1952) but little has been done to assess the validity of this characteristic as a means of determining sex in various age-groups. This study revealed that almost all Garrison goldeye beyond age III can be accurately sexed by examination

of this fin. Fish of age III average 9.5 inches total length.

Within age-group II, the fin characteristic proved reliable in sexing 46.8% of goldeye taken. However, this work was conducted in August, and older fish of age II were more sexually mature. If this sample had been taken earlier in the year, the number of age II fish which could be sexed by this feature would no doubt have been lower. Separate comparisons were not made between the number of males and females exhibiting the characteristic fin development, and, therefore, earlier maturing males may have increased the number of dimorphic fish in the younger age-groups.

Fecundity

The fecundity of Garrison goldeye was low and ova counts averaged 6,531 eggs per female. By comparison, Battle and Sprules (1960) reported that the number of eggs from goldeye in several Manitoba lakes ranged from 5,800 to 25,200, and averaged 14,150. The fecundity of Fort Peck goldeye was nearly the same as that determined for Garrison, according to Hill (1965) who found that the number of eggs per female ranged from 4,288 to 10,164, and averaged 6,913. Despite lower fecundity and the fact that only a segment of the mature females spawn each year, extremely successful reproduction must occur, as evidenced by annual year-class strength and the large population in Garrison.

Spawning activity, duration, and movement

Goldeye ova are non-adhesive and bathypelagic, or semi-buoyant (Battle and Sprules, 1960), characteristics which make reproductive

success independent of water levels, shoreline gradients, bottom composition, or littoral vegetation. Therefore the species is ideally adapted to large impoundment conditions. Benson (in press), with regard to Missouri River impoundments, has stated: "Those species that have eggs that are either semi-buoyant or limnetic, such as freshwater drum or goldeye, have had quite regular year-class abundance." Success of the latter species in Garrison can be attributed, in part, to the spawning characteristics.

It has been postulated that only a portion of all adult females spawn in any given year, and that many mature fish spawn in alternate years. Hinks (1943) first confirmed this on Lakes Winnipeg and Winnipegosis, finding that approximately half of the female goldeye, 12 inches or longer, spawned in any one year. In the present study, intensive netting of spawning populations revealed that 25.8% of all mature females were gravid, and represented only 13.3% of the total goldeye catch. Therefore, these results are in accord with Hinks observations.

Gravid age III females were not taken from Garrison, and the majority of goldeye studied for fecundity were age IV. Age-groups III and IV were represented about equally in the small sample of ripe males. This is in agreement with the observation of Battle and Sprules (1960) that males reach sexual maturity one year prior to females. In Lake Claire, Alberta, they found that males matured between six and nine years, and females between seven and ten. However, these authors stated that the age at maturity is advanced two or three years in southern Manitoba, and may be further advanced in the southern

part of the goldeye range in the United States. Hill (1965) reported that most gravid females taken in the Fort Peck area, Montana, were of age IV, while ripe males were mostly age III.

All efforts to collect spawned ova from open waters or weathered beaches failed, due largely to inadequate sampling gear, the vastness of the water mass, and strong, alternating winds during the spawning period. However, larger diameter planton nets, towed at varying depths during periods of calm, may provide adequate collections of ova.

The duration of the spawning period in Canadian waters is from shortly after ice-cut until the early part of July, and is dependent on water temperatures prevailing in the shallow inshore spawning areas (Battle and Sprules, 1960). In the present study, fish were not collected immediately after the ice cover disappeared, and the onset of spawning was not observed. Gravid females in the catch declined steadily in a period from 22 June to 5 July, and were absent from the catch after the latter date; therefore, the termination of the spawning period agrees with that reported by Battle and Sprules.

During the spawning period, it was observed that the total catch of goldeye varied greatly in the same area on successive days. Large numbers of fish would be taken one day, often followed by a meager catch at the same location on the following day. Some of these catches were composed almost entirely of large, mature fish, while the successive day's catch was predominately immature fish. On numerous occasions, there was uniformity of total length in the daily catch which averaged nine to eleven inches, while the subsequent day's catch often contained mature fish ranging from eleven to thirteen inches.

These observations may indicate schooling of goldeye by year-classes, and suggest that constant movement of these schools was prevalent. This hypothesis is supported by the fact that in some catches large numbers of mature fish were of extremely large size, ranging from twelve to fourteen inches. Few fish of this size were taken in the open waters of the bay in 1966, but a large number was captured in Moccasin Creek in the spring of 1967. Whether these fish represented a spawning accumulation of larger goldeye native to the bay, or were a migrational group from elsewhere in the reservoir, could not be determined.

A distinct temperature gradient was present in the surface waters, and temperatures gradually increased from the main reservoir westward to the more sheltered areas of Moccasin Bay. Averages obtained during the period of spawning showed that Moccasin Creek was approximately 1.5 Celcius warmer than the waters of Mossett Bay, nearer to the main reservoir. Both areas were sampled during the spring season; 13.3% of the catch in Moccasin Creek was gravid females, while only 2.8% of the Mossett Bay catch was gravid females. The two areas were not sampled concurrently throughout the spawning season, and the Mossett Bay location may have been sampled before spawning activity had reached its peak; however, in larger impoundments where temperature differentials exist, available evidence pointed to spawning movement toward areas of increased temperatures.

Stomach analysis and feeding habits

Goldeye are chiefly insectivorous. This has been reported by previous investigators (Grosslein and Smith, 1959), and in the present

study adult terrestrial insects were found to be the principal food organisms. Coleopteran species were encountered most frequently, principally members of the family Chrysomelidae. Few aquatic insects were noted, but several samples contained fair numbers of deep water dipteran larvae of the family Chironomidae. Two goldeye had fed entirely on plankton; their stomachs were filled with cladoceran remains. Small yellow perch were noted in the diets of only three fish.

Goldeye were found to be nocturnal, surface feeders, that could be observed splashing at the surface from dusk to dawn (Peterson, 1967). Most food organisms that were present in the stomachs would normally be more concentrated in the surface waters at night. Other investigators have noted similar, nocturnal foraging in surface waters (Bajkov, 1930; Grosslein and Smith, 1959). Feeding activity appeared to correspond with the period of decreased light intensity, and a period of reduced wind velocity when insects fall to the water surface. However, the presence of chironomids and perch in some stomachs indicated that goldeye on occasion fed in deeper water. Peterson (1967) speculated that food availability may exert greater influence on goldeye depth distribution than does light intensity.

Stomach contents of goldeye taken in the same catch revealed great differences in the composition of organisms. Some samples were comprised principally of coleopterans, while others were chiefly chironomids or cladocerans. This variance might have reflected individual diet preferences, but if schooling and constant school movement occurred, it is possible that feeding took place at different locations and that the catch contained individuals taken from several schools.

Benson (in press) discussed reservoir species and their principal foods, and listed bottom fauna and fish as the major diet of goldeye. This may apply to goldeye in the lower Missouri River impoundments, but is apparently at variance with the present findings for Garrison. Goldeye from Lewis and Clark Lake and the lower Missouri River exhibited faster growth rates (Claflin, 1963) than the goldeye of Garrison. Therefore, foods listed by Benson and their relative abundance in the reservoirs may explain differential growth rates between the two areas.

Parasites

A very high incidence of helminths was found in the alimentary tracts of Garrison goldeye. All of the parasites recovered appeared to be of one species, Bothriocephalus cuspidatus Cooper, 1917, a pseudophyllidean cestode common across Canada and the northern United States in a number of freshwater fishes, including goldeye and mooneye, Hiodon tergisus LeSueur (Larson, personal communication). Stained specimens did not agree with Bothriocephalus texomensis, N. Sp., described from Oklahoma goldeye by Self (1954). Essex (1928) reported that the larvae of this cestode develop in the haemocoel of various copepods, cyclops. He found no indication of a second intermediate host; therefore, the presence of this parasite in the population confirms the reported feeding on plankton by goldeye.

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